Ramesh

The Tesla “Sum of Squares” Bug

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1 Introduction

Recently, an error was discovered in the way statistics were being computed in Tesla. To quote, “This find impacts the Rubix BE deliverables profoundly.”

The Q implementation of the Tesla back-end suffered from the same bug. In this document, we describe how the bug was fixed using Q. I would like to draw the reader’s attention to:

1. The simplicity of the solution — it is no more than a few lines of code
2. The efficiency of the solution — the run times are within reason

The conclusion is that **agility** is a key requirement of any analytics solution we put together. This is not the first time nor the last time that changes will need to be made to the way we transform data. We will need to respond to the business in days, not weeks.

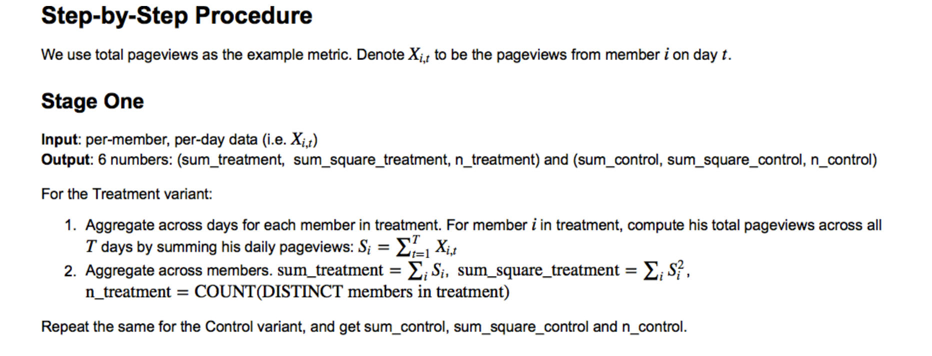
Even in this case,

- we thought we had fixed the bug (Section 5).
- then we found that there wasn’t an agreement on what the fix should be (Section 6).
- this required us to implement another solution (Section 7).

I find myself these days preaching about the lessons engineers can learn from the humanities. Here is a quote which illustrates the point [1].

Let your boat of life be light, packed with only what you need . . . You will find the boat easier to pull then, and it will not be so liable to upset, and it will not matter so much if it does upset; good, plain merchandise will stand water. You will have time to think as well as to work.

[1] Three Men in a Boat by Jerome K. Jerome



Step-by-Step Procedure

We use total pageviews as the example metric. Denote $X_{i,t}$ to be the pageviews from member i on day t.

Stage One

Input: per-member, per-day data (i.e. $X_{i,t}$)
Output: 6 numbers: (sum_treatment, sum_square_treatment, n_treatment) and (sum_control, sum_square_control, n_control)

For the Treatment variant:

1. Aggregate across days for each member in treatment. For member i in treatment, compute his total pageviews across all T days by summing his daily pageviews: $S_i = \sum_{t=1}^{T} X_{i,t}$
2. Aggregate across members. $\text{sum\_treatment} = \sum_i S_i$, $\text{sum\_square\_treatment} = \sum_i S_i^2$, $\text{n\_treatment} = \text{COUNT(DISTINCT members in treatment)}$

Repeat the same for the Control variant, and get sum_control, sum_square_control and n_control.

Figure 1: Tesla Spec

2 The Bug

Quoting Omar, "we found a bug in the cross-day aggregation logic where the total square is being calculated incorrectly." Details in https://iwww.corp.linkedin.com/wiki/cf/x/_zGwB

Further, "The change required to implement the new logic is large because the cubes and queries were optimized based on the "current computation" logic. The correct computation would require that we maintain the member level information (associated with the metric) and this results in a massive increase in space and computation."

3 The Spec

The "correct" specification is in Figure 1, borrowed from https://iwww.corp.linkedin.com/wiki/cf/x/_zGwB

4 The Data Model

Recall that Q is a column-store database. The data model we use

1. stores each day's data in a separate table
2. for a given date,
   (a) each row corresponds to a member who visited the site that day
   (b) we have one column for each metric (some cells may be null)

(c) we have one column for each experiment that was alive that day, the values being the different treatments (some cells may be null). The values may also be a combination of treatment and segment. In either case, we do not anticipate more than 256 different values for a given experiment column.

Let us do some back-of-the-envelope calculations to assess the storage needs of this data model. Assume

1. 32M members per day, 2^{25}
2. 512 metrics 2^9
3. 4096 experiments, 2^{12}
4. a metric can be stored in an average of 1 byte (some will be 2 bytes, some will be 1 bit)
5. an experiment can be stored in 1 byte
6. assume 32 days in a month, 2^5

This means that a month’s data is $2^5 \times 2^{25} \times (2^2 + 2^9 + 2^{12}) \approx$ 4 TB. We do not believe that this is excessive

5 The Fix

As Omar indicates, we need to accumulate the values of the metric for **each** member, over the desired time period, **before** squaring it. The following code does the job. In this example,

- We used *number of page views* as the metric. m75 is our internal name for it.
- We used *search-voltron-use* as our experment. `fk_lkp_treatment_1` is our internal name for it.
- We used the first 7 days of May as our test period
- It takes approximately one second to process one metric over one day.
- Current implementation stores the metric as 4-bytes. Given that it is unlikely that a real member would visit more than 32767 pages in a day, this could be stored in 2 bytes. Given that memory access is the dominant cost, this simple compression could cut the time in half.

- We believe that 0.5 seconds/metric/day is within striking distance. Sathya describes a typical calculation s consisting of 50 metrics over the last 14 days. This would take 10 minutes on one machine.

```
date=20130501
mfld=m75
tkfld=fk_lkp_treatment_1
# TM contains member IDs of all members in last 30 days
while [ $date -le 20130507 ]; do
  mtbl=TM$date # contains information about that date
  if [ $iter = 1 ]; then
    q srt_join $mtbl mid $mfld TM mid sum_vals reg
  else
    q srt_join $mtbl mid $mfld TM mid temp_fld reg
    q f1f2opf3 TM temp_fld sum_vals '+' sum_vals
  fi
  date=`expr $date + 1` # use better way to find next date
done
q f1f2opf3 TM sum_vals sum_vals '*' sqr_sum_vals
q delete   TM temp_fld
q countf   TM sum_vals     $tkfld '' lkp_treatment sum_vals
q countf   TM sqr_sum_vals $tkfld '' lkp_treatment sqr_sum_vals
```

6 The Debate

However, the above solution glosses over the fact that a member could change treatment during the lifetime of an experiment. There does not appear to be consensus as to whether it is okay to ignore this. So, the solution in the next section deals with what happens when we need to aggregate by member and treatment (not just by member) before the squaring is done.

7 The Next Fix

There was no significant change in run time for the following approach — about 1 second per metric per day without optimization.

```
date=20130501
mfld=m75
```

```
tkfld=fk_lkp_treatment_1
q delete Tcomp:tempt
mask=16777215 # masks all but lowest 24 bits
while [ $date -le 20130507 ]; do
  mtbl=TM$date
  # compfld = (mid << 32) | (treatment << 24) | metric
  # This means 32 bits for mid, 8 for treatment, 24 for metric
  q pack $mtbl mid:$tkfld:$mfld 32:24:0 I8 compfld
  q set_meta $mtbl compfld sort_type ascending # Dangerous but correct
  if [ $iter = 1 ]; then
    q copy_fld $mtbl compfld ’’ Tcomp
  else
    q t1f1t2f2opt3f3 $mtbl compfld Tcomp compfld pvalcalc "mask=[$mask]" te
    q rename tempt Tcomp
  fi
  q set_meta Tcomp compfld sort_type ascending # Dangerous but correct
  date=‘expr $date + 1‘
done
q f1s1opf2 Tcomp compfld    $mask      ’&’ sum_metric
q f1f2opf3 Tcomp sum_metric sum_metric ’*’ sqr_sum_metric
q f1s1opf2 Tcomp compfld    24 ’>>’ $tkfld
q f1s1opf2 Tcomp $tkfld     255 ’&’ $tkfld

q countf   Tcomp sum_metric     $tkfld ’’ lkp_treatment sum_vals
q countf   Tcomp sqr_sum_metric $tkfld ’’ lkp_treatment sqr_sum_vals
```